Can Digital Financial Inclusion Affect Green Development？An Empirical Analysis Based on China's Provinces

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Abstract

In the information age, how to release the positive effect of finance on green economy is a topic that needs to be answered in the modern economy and society. Based on panel data from 30 Chinese provinces from 2011 to 2020, we evaluate the impact of digital financial inclusion on green development by calculating green total factor productivity and discuss the mechanism of this influence. Our results show that:Digital financial inclusion can significantly promote regional green development, and the coefficients of the three secondary indicators range from large to small as coverage breadth, usage depth and digital support, besides, this impact is mainly reflected in the technological progress of green total factor productivity. Among further test of the mechanism, we discover that digital financial inclusion might indirectly boost the regional green growth by optimizing industrial structure and enhancing technological innovation, when industrial structure rationalization and technical innovation are utilized as threshold variables, there are two and three thresholds for the influence of digital inclusive finance on green development, respectively, which display a nonlinear spillover effect.

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Keywords: Digital financial inclusion, Green development, Green total factor productivity, Industry structure, Technology innovation

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1.Introduction

1.1 Background of the Study

In a world where ecological and resource issues are continually arising, green development affords worldwide economic growth a new direction. During the 40 years of reform and opening up, china's economy has undergone remarkable change. The benefits of economic progress should be reflected not only in higher material living standards, but also in cleaner air, safe water, and a more beautiful living environment.In China's financial sector, digital financial inclusion, which has emerged as a result of the internet, big data, cloud computing and other technologies, has an important role to play. It enhances the probability that getting financial services for groups living in remote areas, as well as youth and female groups (Qi and Li, 2019), provide sufficient financial assurance for the innovation and entrepreneurship for enterprises (Cai andZhu, 2020), and encourages economic growth (Qian et al., 2020), regional innovation (Liang and Zhang, 2019), and income distribution(Xiaoling Song, 2017) significantly, the value of digital financial inclusion for both social and economic development has been acknowledged.

The popularity of green development is not only a profound reflection made by human beings in the face of the severe ecological environment, but also a wish and pursuit of sustainable development. The goal of striving to achieve carbon peaking by 2030 and carbon neutrality by 2060 has put forward higher expectations for pollution reduction in China. Digital financial inclusion has the potential to improve resource allocation, minimize energy consumption in the financial sector, promote green consumption and green growth, and create novel pathways for green and low-carbon development.

1.2 Literature Review

Many relevant studies on digital financial inclusion have been undertaken by scholars. Several more academics believe that digital financial inclusion can contribute to reducing household poverty (Park and Mercado, 2015), increases total factor productivity (Hou and Li, 2020), and supports industrial structure optimization and upgrading (Tang et al., 2019).Green development is impacted by many factors, such as industrial structure (Li and Su, 2016, Liu and Wei, 2020, Xuesheng Zhang, 2022), financial aggregation (Cao and Yu, 2018, Yuan et al., 2019), technology and scientific progress (Huang, 2016, Wang et al., 2017), absorption to the outside world (Huang and Wu,2021, Zhou and Zhang, 2021), and so on.There is a U-shaped relationship between environmental regulation and green development, when environmental regulation becomes more stringent, green development will decline and then rise (Li and Yi et al.,2020).

Digital financial inclusion has green characteristics, and the digitization, intensification, and interconnection of business models can effectively reduce energy consumption in the process of providing financial services (Duan et al., 2021). Fang and Yang (2021) found that financial technological improvements can reduce environmental pollution in urban areas, and this impact is greater within polluted, less economically developed, and marginal cities. Based on data from 283 cities, Xu et al. (2021) examined the relationship between digital financial inclusion and pollution reduction, concluding that it can reduce carbon emissions by influencing enterprise innovation and entrepreneurship as well as improving industrial structure. By increasing the effectiveness of funding and encouraging green technological innovation, Lv et al. (2021) note that digital financial inclusion makes the industrial become more environmentally friendly.

Just several papers have discussed the essential link between digital financial inclusion and green development so far. Can digital financial inclusion give green development more power? With the previous context, we will explore the connection between digital financial inclusion and green development from the perspective of provinces. The innovations of this paper may be as follows: Firstly, we explore the incentive effect of digital financial inclusion on green development, providing a new perspective for subsequent academic research. Secondly, from the perspectives of industrial structure and technology innovation, we detail the specific mechanism of digital financial inclusion impact on green development, presenting policy suggestions that might be used to encourage the comprehensive combination of real economy with digital financial inclusion. The remaining part of this essay is listed as following: The theoretical mechanisms and research hypotheses are presented in Section 2, the research design is presented in Section 3, the empirical analysis is presented in Section 4, the mechanism test and nonlinear analysis is presented in Section 5, and the conclusions and implications are presented in Section 6.

2.Theoretical Mechanisms and Research Hypotheses

2.1 The Direct Impact of Digital Financial Inclusion on Green Development

Listed below are ways in which digital financial inclusion can impact on green development.

The first is that the inclusiveness of digital financial inclusion provides guarantee for green technology innovation of small and medium-sized enterprises (MSMEs). Conventional financial services favor large businesses with substantial assets, due to the lack of real assets and guarantees, MSMEs usually have a hard time to gain effective financial service support from financial institutions, which limits their ability to create and grow(Wan et al., 2020). Using digital technology, digital financial inclusion evaluates MSMEs' credit quickly and accurately. Digital financial inclusion raises the likelihood that businesses could be eligible for bank loans and financing, which may enable MSMEs to realize technological innovation and support environmental improvements consequently. According to data from the central bank, China's total green loan balance in local and foreign currencies was 15.9 trillion yuan in 2021, climbing 33% of the previous year, deepening fintech support for green loans in the clean energy industry is expected to be a future trend of digital financial inclusion. Second, platformization of digital financial inclusion enables users to participate in environmental protection in more scenarios. Let's take Ant Forest as an example: By paying with alipay, customers can plant a virtual tree in the application interface, while a real tree will then be planted in the desert improvement area. From the data released by the ministry of ecology and environment in 2021, we know that ant forest has planted 326 million trees, leading 613 million people to join environmental public welfare activities online. Finally, people have been able to redefine their eco-friendly lifestyles owing to the convenience of digital financial inclusion(Huang and Huang,2018). Each trading platform has implemented programs for recycling, sorting trash, and second-hand sales, which cut down resource waste and make joint efforts with users to create green world.

Hypothesis 1: Green development may be encouraged by the expansion of digital financial inclusion.

2.2 Analysis of the Mechanism of Digital Financial Inclusion Affecting Green Development

Digital financial inclusion can promote industrial structure upgrading, primarily through the channels of factor allocation and consumer demand.

Financial institutions absorb deposits to complete the initial accumulation of capital, adjust the quantity of capital factor inputs needed by enterprises, optimize the allocation of credit funds among industries, and promote industrial structure upgrading in the process of digital financial inclusion development(Bruhn and Love,2014). The diversification of financial products stimulates residential consumption,which also results in the modernization and restructuring of industrial structure. The industrial structure optimization has a positive effect on green development. Along with the modification of the primary engine of economic growth,the flow of labor, capital, and other production factors among industries encourages the adjustment in industrial structure, a considerable number of production factors flow from secondary to tertiary industries. Furthermore, as old manufacturing methods are innovated and modern production methods are utilized, products get green extra value, which is conducive to the sustainable development of the economy and the improvement of the ecological environment.

Hypothesis 2: Digital financial inclusion drives regional green development by promoting industrial structure optimization and upgrading.

Digital technologies can access a large amount of data (Gomber et al.,2018), allowing digital financial inclusion to provide adequate information to both the supply and demand for funds while also reducing transaction risks in the process of providing financial services, thereby creating an ideal environment for business innovation (Demertzis et al.,2018).Green development can benefit from technological innovation. On the one hand, scientific and technological innovation has resulted in advanced environmental technologies, which play an important role in protection of the environment. On the other hand, technological innovation has revolutionized the traditional industrial development model that relied on labor and resources, produced green products with minimal pollution and energy consumption, and guided residents in developing a green and sustainable lifestyle.

Hypothesis 3: Digital financial inclusion drives regional green development by boosting technological innovation.

3.Study Design

3.1 Sample Selection and Data Sources

Based on the connotation and nature of digital financial inclusion, scholars have established the framework of digital financial inclusion indicators in various ways. Among these, the index co-compiled by Peking University's and Ant Financial Services Group has become publicly recognised and used, it measures the growth of digital financial inclusion in China's provinces , cities, and counties accurately and completely. Because this data was released in 2011, we used it as the study's starting point. Green development can be measured in three ways: calculating green GDP, constructing a comprehensive index system, and calculating green development efficiency. In this study, we apply the Slack Based Measure(SBM)with directional distance function(DDF) approach, add non-desired outputs to the model, and then combine with the Malmquist Index(ML) to construct the green total factor productivity (GTFP) of each region to represent the green development. It is crucial to highlight that the data for the non-desired output indicators used in the estimation of GTFP are currently updated to 2020, so we've limited the study's time span to that year. Meanwhile, we excluded Tibet, Hong Kong, Macao, and Taiwan from the analysis because there are more omissions in the data for these locations. Finally, we chose a sample of 30 Chinese provinces from 2011 to 2020 for this study, a total of 300 observations. The environmental data is sourced from the China Environmental Statistics Yearbook, the foreign direct investment data is sourced from the Wind, and the remaining data is sourced from the China Statistical Yearbook and Regional Statistical Yearbooks, finally, we utilize linear interpolation to replenish the vacant data.

3.2 Variable Design and Description

3.2.1 Explained Variable

Fare (1997) combined the DDL with ML to calculate total factor productivity and introduced the concept of green total factor productivity. On this basis, Tone (2001) and others applied the SBM method to optimize the calculation of total factor productivity and got more accurate estimation results. Later, Oh (2010) constructed the GML having transferable and cumulative characteristics, which made the measurement results more closely match the real conditions. Referring to the studies of Zhao et al.(2020), Li and Xin(2020), we use the SBM-GML approach to calculate green total factor productivity.

The indicators involved in GTFP are selected as follows.

(1)Input indicators include labor factor, capital factor and energy factor(Table 1).

The majority of the reviewers used the amount of absolute employment to assess labor input, while Cui and Lin(2019) chose the average annual number of employees in firms, Liu and Xin(2018) chose the total number of employed people in the society at the end of the year. In this paper, we choose the number of employed persons at the end of the year in each province to measure the input of labor factors.

Capital input is measured with the fixed capital stock of whole society, which is estimated using the perpetual inventory method for the base period of 2000. The formula is as follows.

$$Cap_{it} = (1 - \delta_i)Cap_{i,t-1} + I_{it} \quad (1)$$

Cap indicates the fixed capital stock, δ indicates the capital depreciation rate (9.6%), *I* indicates the total fixed asset formation. Since the value of fixed asset investment is not updated after 2018, we choose to use the growth rate of fixed asset investment to calculate the fixed asset investment for 2018-2020.
The energy element is measured by total energy consumption.

(2)Output indicators include expected and non-expected output
Expected output is measured by real GDP (2010 as the base period). The emissions of wastewater, SO_2 and general industrial solid waste were selected to measure the non-expected output.

Table 1:Input and Output Indicators of Green Total Factor Productivity

Indicator Type	Indicator Name	Indicator Description
Input Indicators	Labor	Number of Employed
	Energy	Total Energy Consumption
	Capital	Total Fixed Capital Formation
Output Indicators	Expected	Real GDP
	Non-Expected	Industrial Wastewater Discharge
		Industrial SO_2 discharge
		General Industrial Solid Wastes Discharge

The calculations of the chain growth rate of green total factor productivity by region are shown in the Table 2.

Table 2:Calculation of Chained Growth Rate of GTFP for 30 Provinces

Province	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Beijing	1.003	1.000	1.013	1.015	1.034	1.040	1.086	1.083	1.000	1.000
Tianjin	1.000	1.000	1.008	0.998	1.006	1.053	1.016	1.012	1.013	1.283
Hebei	0.998	0.997	0.999	1.002	1.008	1.011	1.031	1.023	1.035	1.121
Shanxi	1.003	0.992	0.993	0.992	0.995	1.003	1.012	1.010	1.009	1.014
Neimenggu	0.997	1.000	0.995	0.992	1.005	1.011	1.006	1.006	1.005	1.008
Liaoning	0.996	0.997	1.001	0.997	1.006	1.005	1.014	1.027	1.029	1.015
Jilin	0.999	1.000	1.004	0.999	1.002	1.020	1.002	1.014	1.003	1.019
Heilongjiang	1.001	0.986	0.997	1.004	1.003	1.011	1.008	1.005	1.011	1.017
Shanghai	1.019	1.025	1.008	1.030	1.022	1.044	1.097	1.128	1.000	1.000
Jiangsu	1.018	1.022	1.022	1.023	1.024	1.029	1.052	1.055	1.172	1.000
Zhejiang	1.017	1.017	1.018	1.016	1.018	1.029	1.031	1.038	1.036	1.065
Anhui	0.998	0.998	0.998	0.998	0.998	1.004	1.004	1.002	1.014	1.024
Fujian	0.996	0.996	1.000	0.997	0.999	1.002	1.018	1.013	1.016	1.037
Jiangxi	0.997	0.999	0.998	0.998	0.997	0.999	1.010	1.004	0.988	1.007
Shandong	1.013	1.014	1.022	1.012	1.010	1.017	1.031	1.029	1.034	1.070
Henan	0.998	1.003	1.010	1.008	1.008	1.027	1.042	1.021	1.136	1.288
Hubei	0.997	0.997	1.003	0.998	1.000	1.019	1.022	1.025	1.025	0.997
Hunan	0.994	0.997	1.002	0.998	0.999	1.020	1.030	1.034	1.039	1.155

Guandong	1.145	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Guangxi	0.998	0.996	0.999	0.997	0.999	1.009	0.997	0.999	0.999	1.005
Hainan	0.887	0.970	0.993	0.958	1.010	1.210	1.000	1.000	1.000	1.000
Chongqing	1.003	1.003	1.007	0.999	1.002	1.024	1.002	1.008	1.007	1.011
Sichuan	1.003	1.002	1.003	0.998	1.010	1.018	1.022	1.026	1.014	1.022
Guizhou	0.985	0.991	0.997	0.989	0.998	1.012	0.995	1.000	1.000	1.005
Yunnan	0.991	0.999	1.001	0.996	0.998	0.997	1.014	1.000	0.997	1.004
Shanxi	0.999	1.011	1.001	0.995	0.995	1.005	0.998	1.008	0.994	1.001
Gansu	0.985	0.996	0.994	0.995	0.998	1.016	1.004	1.003	1.006	1.018
Qinghai	1.000	0.934	1.070	1.000	0.898	1.113	1.000	0.897	0.997	1.117
Ningxia	0.949	1.005	0.986	0.988	0.992	1.017	1.007	0.990	1.004	1.336
Xinjiang	0.988	0.989	0.987	0.995	0.997	1.011	0.997	1.005	1.000	1.003

To obtain the absolute value of GTFP, we perform the following treatment: Let the value of green total factor productivity in 2010 as 1, then the absolute value of green total factor productivity in a given year is equal to the continuous product of 1 and the chain growth rate of the corresponding year. For example, the GTFP in 2015 equals '1 × the chain rate of increase in 2011 ×⋯ × the chain rate of growth in 2015', and we calculate the absolute values of technical progress (TC) and technical efficiency (EC) in the same way.

Plotting the time-series variation of green total factor productivity in each region. As we can see, the GTFP of most provinces produces a significant change between 2016 to 2020, which is due to the fact that after the 18th Congress of China, Green became the keyword of development, and the execution of various environmental protection measures has enhanced green total factor productivity in all regions as China toward to the aim of green development.

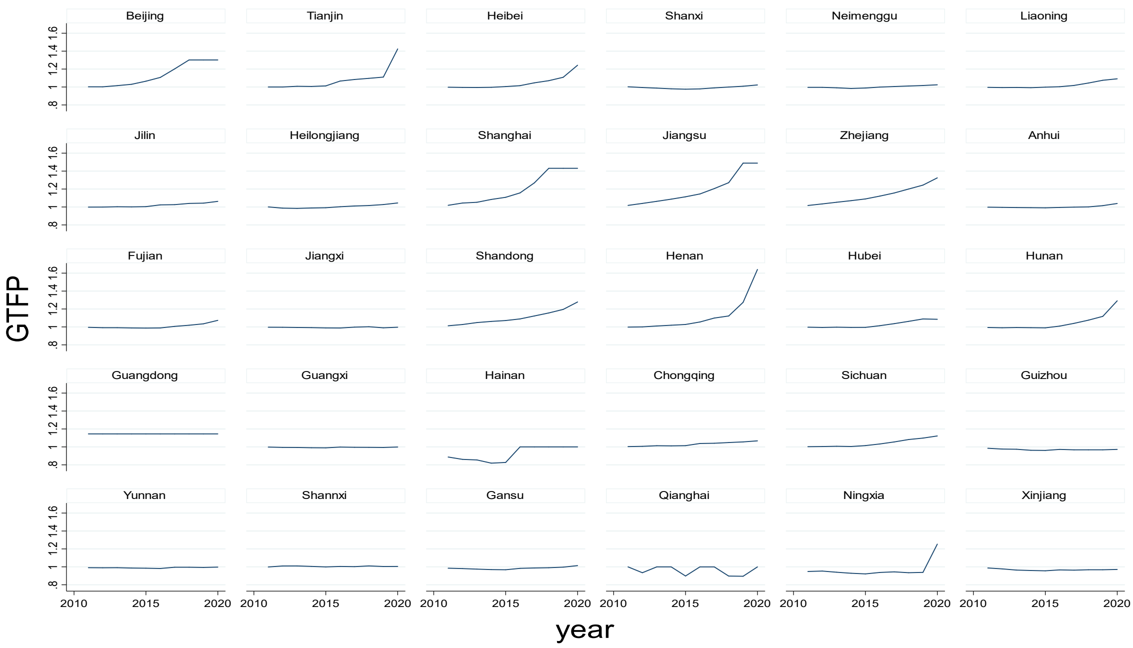

Figure 1:Time Trends of GTFP in 30 Provinces

3.2.2 Explanatory Variable

The digital financial inclusion index is derived from finance research center of Peking University, which includes one primary indicator (DFI) and three secondary indicators: breadth of coverage (COV), depth of use (USA), and degree of digitization (DIG).

3.2.3 Mechanism Variables

(1) The effect of industrial structure optimization

The optimization of industrial structure includes the industrial structure rationalization and industrial structure supererogation.

Rationalization of industrial structure refers to the coordination among industries, which requires the adjustment of the unreasonable industrial structure, so that resources can be reasonably allocated in various industries. Researchers generally use the structural deviation degree to measure the industrial structure rationalization, and the formula is :

$$E = \sum_{i=1}^{n} \left| \frac{Y_i/L_i}{Y/L} - 1 \right| = \sum_{i=1}^{n} \left| \frac{Y_i/Y}{L_i/L} - 1 \right| \quad (2)$$

E is structural deviation, Y is output, L is employment, i is industry, and n is the number of industrial sectors. Y/L is productivity, Y_i/Y is output structure, L_i/L is employment structure. Classical economics argues that the economy will eventually reach balance, so Y_i/L_i equals Y/L, E equals 0. However, this degree fails to take into account how different each industry's contribution to the economy is. On this basis, the Thiel index is optimized as follows:

$$TL = \sum_{i=1}^{n} \left(\frac{Y_i}{Y_i}\right) ln\left(\frac{Y_i/Y}{L_i/L}\right) \quad (3)$$

As previously stated, the economy reaches equilibrium when the Thiel index = 0. To simplify the subsequent analysis, we use 1/TL to turn industrial structure rationalization into a positive indicator.

The industrial structure supererogation refers to the industrial structure's evolution in the direction of primary, secondary, and tertiary industries, which is typically quantified by Clark's law. In the process of industrial structure supererogation, the growth rate of tertiary industry is faster than primary and secondary industry. The percentage of tertiary sector production to secondary sector output, indicated as TS, is used as a metric of industrial structure supererogation. The higher value of TS, the more advanced the industrial structure.

(2) The effect of technology innovation

Innovation includes input, output and benefits. Input in terms of individuals, funding and equipment, output refers to the innovation product obtained by using the factors of production, such as patents, papers, etc, benefits refers to the economic and social rewards brought by innovation behavior, such as enterprise profits, income from the selling of new items, etc. Since patent examinations will take a long time, the process from technology to product and then sales on the platform is easily disturbed by production costs, social acceptance and other factors.Therefore, we choose the patent application number to measure technology innovation(Tech).

3.2.4 Control Variables

Government behavior, opening up, foreign direct investment, infrastructure building, human capital level, and urbanization level are introduced as control variables in the regression based on past research. Where, governmental actions are expressed as the ratio of local general budget expenditures to regional GDP, noted as Gov. Foreign openness is expressed as the ratio of total imports and exports to regional GDP, noted as Open. Foreign direct investment is expressed as the ratio of foreign direct investment to regional GDP, noted as Fdi. Infrastructure development is denoted as road person ratio, denoted as Road. Human capital is denoted as the number of students in higher education per million people, denoted as Edu. Urbanization level is denoted as the ratio of urban population to total population, denoted as Urban.

Table 3:Definition of Variables

Type	Name	Symbols	Definitions
Explained Variables	Green Development	Green	SBM-GML for Calculating Green Total Factor Productivity
Explanatory Variables	Digital Financial Inclusion	DFI	Indices from Peking University
	Coverage Breadth	Cov	
	Use Depth	Usg	
	Digitization Support	Dig	
Mechanism Variables	Industrial Structure Rationalization	TS	$\frac{1}{\sum_{i=1}^{n}(\frac{Y_i}{Y_i})\ln\left(\frac{Y_i/Y}{L_i/L}\right)}$
	Industrial Structure Supererogation	TL	$\frac{\text{Tertiary Industry Production}}{\text{Secondary Industry Production}}$
	Technology Innovation	Tech	Patent Application Number
Control Variables	Government Actions	Gov	$\frac{\text{General Budget Expenditures}}{\text{GDP}}$
	Opening Up	Open	$\frac{\text{Total Imports And Exports}}{\text{GDP}}$

	Foreign Direct Investments	Fdi	$\frac{\text{Foreign Direct Investment}}{\text{GDP}}$
	Infrastructure Construction	Road	Road Person Ratio
	Human Capital	Edu	The Number Of Students In Higher Education Per Million People
	Urbanization	Urban	$\frac{\text{Urban Population}}{\text{Toal Population}}$

3.3 Model Construction

In order to explore the correlations between digital financial inclusion and green development, we conduct a preliminary study employing the following regression:

$$Green_{it} = \alpha_1 + \beta_1 DFI_{it} + \theta_1 Control_{it} + \lambda_i + \mu_t + \varepsilon_{it} \quad (4)$$

$$EC_{it} = \alpha_1 + \beta_1 DFI_{it} + \theta_1 Control_{it} + \lambda_i + \mu_t + \varepsilon_{it} \quad (5)$$

$$TC_{it} = \alpha_1 + \beta_1 DFI_{it} + \theta_1 Control_{it} + \lambda_i + \mu_t + \varepsilon_{it} \quad (6)$$

i is region, t is time, $Green$ indicates green development level measured by GTFP, EC and TC indicates technical efficiency and technical progress, DFI indicates digital financial inclusion, $Control$ is a set of control variables, λ is individual effect, μ is indicates time effect. In this paper, the standard errors are clustered at the region level.

Referring to the studies of Jiang (2022), Tang (2022), theoretical analysis was used to elaborate the relationship between the explanatory variables and the mechanism variables (Section 2),the model below evaluated the link between the explanatory variables and the mechanism variables.

$$TL_{it} = \alpha_1 + \beta_1 DFI_{it} + \theta_1 Control_{it} + \lambda_i + \mu_t + \varepsilon_{it} \quad (7)$$

$$TS_{it} = \alpha_1 + \beta_1 DFI_{it} + \theta_1 Control_{it} + \lambda_i + \mu_t + \varepsilon_{it} \quad (8)$$

$$Tech_{it} = \alpha_1 + \beta_1 DFI_{it} + \theta_1 Control_{it} + \lambda_i + \mu_t + \varepsilon_{it} \quad (9)$$

TL、TS、$Tech$ indicates the rationalization of industrial structure, industrial structure supererogation and technological innovation.

Further, a non-linear analysis is performed:

$$Green_{it} = \mu_i + \beta_1^{'} x_{it} I(TL \le \gamma) + \beta_2^{'} I(TL > \gamma) + e_{it} \quad (10)$$

$$Green_{it} = \mu_i + \varphi_1^{'} x_{it} I(TS \le \gamma) + \varphi_2^{'} I(TS > \gamma) + e_{it} \quad (11)$$

$$Green_{it} = \mu_i + \omega_1^{'} x_{it} I(Tech \le \gamma) + \omega_2^{'} I(Tech > \gamma) + e_{it} \quad (12)$$

4.Empirical Results and Analysis

4.1 Descriptive Statistics

The results of descriptive statistics of the variables are shown in the Table 4.Before analysis, we test whether there is multicollinearity among the variables, the results show that the inflation factors of each variable are less than 10, indicating that multicollinearity does not exist(Table 5).

Table 4:Descriptive Statistics

Variables	Mean	Variance	Min	Max
Green	1.038	0.103	0.819	1.641
DFI	0.217	0.097	0.018	0.432
Cov	0.198	0.096	0.002	0.397
Usa	0.212	0.098	0.007	0.489
Dig	0.290	0.118	0.008	0.462
Gov	0.251	0.104	0.110	0.643
Open	26.534	29.581	0.764	154.816
Fdi	2.015	1.690	0.010	10.093
Road	15.896	4.799	4.040	26.780
Edu	2.641	0.805	1.082	5.613
Urban	0.590	0.122	0.350	0.896
TS	0.099	0.128	0.013	1.266
TL	1.324	0.729	0.527	5.244
Tech	0.102	0.144	0.001	0.967

Table 5:Multicollinearity Test

Variable	VIF	1/VIF
DFI	1.830	0.548
Gov	1.560	0.640
Open	3.440	0.291
Fdi	1.540	0.650
Road	1.500	0.665
Edu	2.560	0.390
Urban	5.430	0.184
MeanVif	2.550	

4.2 Regression Analysis

The influence of digital financial inclusion on green development is examined by using fixed effects model, and the estimate results are shown in Table 6. As seen in the columns (1) and (2), the development of digital financial inclusion shows a significant positive impact on the green development , and the model fits better after the time-effect has been controlled. the estimated coefficient of DFI is 3.250, which is significant at the 1% level. Using EC and TC as explanatory variables, the regression results are shown in columns(3)and(4), digital inclusion remains showing a promotion of technological progress at a significant level of 1%,but technical efficiency has not appeared as such. This suggests that digital financial inclusion has an influence on green development primarily by improving the level of technology. However, under the current technological level, diverse resources have been unable to achieve acceptable allocation, and technical efficiency has not been able to become the major road to encourage green development.

Table 6:Results of the Impact of Digital Inclusive Finance on Green Development

Variable	(1) Green	(2) Green	(3) TC	(4) EC
DFI	0.001***	0.003***	0.003***	0.000
	(0.000)	(0.001)	(0.001)	(0.001)
Gov	-0.344***	-0.091	-0.116	0.215*
	(0.113)	(0.107)	(0.148)	(0.123)
Open	-0.000	-0.001	-0.001	-0.000
	(0.001)	(0.001)	(0.000)	(0.000)
Fdi	-0.007*	-0.011**	-0.012***	-0.001
	(0.004)	(0.004)	(0.004)	(0.002)
Road	-0.006**	-0.005**	-0.006***	0.001
	(0.003)	(0.002)	(0.002)	(0.002)
Edu	0.013	0.003	0.017	0.037
	(0.023)	(0.022)	(0.020)	(0.037)
Urban	0.061	0.045	0.142	0.055
	(0.148)	(0.160)	(0.144)	(0.190)
_cons	1.050***	1.0345***	1.137***	0.830***
	(0.062)	(0.067)	(0.075)	(0.082)
Code	YES	YES	YES	YES
Year	NO	YES	YES	YES
Obs	300	300	300	300
R^2	0.335	0.566	0.591	0.156

(Note: ***, ** and * indicate that the data are significant at the 1%, 5% and 10% levels, the numbers in parentheses are standard errors.)

Furthermore, the three secondary indicators of coverage breadth, usage depth, and digital support were regressed as core explanatory variables. The estimation results show that digital financial inclusion and each of its sub-indices have positive impact on green development. Estimated coefficients of the three indicators in descending order are breadth of coverage, depth of use, and digital support, the coefficient of coverage breadth is higher than other two indicators significantly, which indicates that the impact of digital financial inclusion on green development is mainly generated through the expansion of breadth of coverage.

Table 7:Regression Results of the Impact of Three Secondary Indicators of Digital Financial Inclusion on Green Development

Variable	(1)	(2)	(3)	(4)
	Green	**Green**	**Green**	**Green**
DFI	0.003***			
	(0.001)			
Cov		0.002**		
		(0.001)		
Usa			0.001***	
			(0.000)	
Dig				0.001***
				(0.000)
Gov	-0.091	-0.310***	-0.148	-0.323***
	(0.107)	(0.104)	(0.113)	(0.097)
Open	-0.001	-0.001	-0.001	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Fdi	-0.011**	-0.008**	-0.011**	-0.007
	(0.004)	(0.004)	(0.005)	(0.005)
Road	-0.005**	-0.008***	-0.005**	-0.007***
	(0.002)	(0.002)	(0.002)	(0.002)
Edu	-0.003	-0.014	0.002	-0.013
	(0.022)	(0.020))	(0.021)	(0.018)
Urban	-0.045	-0.065	0.118	0.268
	(0.160)	(0.174)	(0.153)	(0.165)
_cons	1.0345***	1.208***	1.007***	1.019***
	(0.067)	(0.073)	(0.082)	(0.072)
Code	YES	YES	YES	YES
Year	YES	YES	YES	YES
Obs	300	300	300	300
R^2	0.566	0.503	0.517	0.531

4.3 Robustness Test

We choose to perform robustness test by three ways: replacing the explained variables, replacing the explanatory variables and replacing the model. We used green total factor productivity to symbolize green growth in the prior work. In this case, we select 15 indicators from three dimensions: green economy, green society, and green life (Table 8), and use the entropy method to construct a comprehensive index to remeasure the green development, because the indicator of Environmental pollution treatment investment is revised only till 2018, so this part only includes 240 samples from 2011 to 2018.The results are shown in Table 9 column (1), the estimated coefficient of digital financial inclusion on green development is still significantly positive after changing the measurements of the variables.

Table 8 :15 Indicators of the Green Development Composite Index

Indicator Layer	Specific Indicators	Measurement Method
Green Economy	R&D Funding investment	$\frac{R\&D\ Expenses}{GDP}$
	Number of granted patent applications	/
	Foreign Trade Openness	$\frac{Import\ and\ Export\ Total}{GDP}$
	Foreign Trade Dependency	$\frac{Foreign\ Direct\ Investment}{GDP}$
	Urbanization Rate	$\frac{\text{Urban Population}}{\text{Toal Population}}$
	Urban-Rural Consumption Coordination Level	$\frac{\text{Consumer Spending of Urban Residents}}{Consumer\ Spending\ of\ Rural\ Residents}$
	Ratio of Urban and Rural Disposable Income	$\frac{Disposable\ Income\ of\ Urban\ Residents}{Disposable\ Income\ of\ Rural\ Residents}$
Green Living	Forest coverage	/
	Exhaust Emissions Per Unit of GDP	$\frac{SO_2\ Emissions}{GDP}$
	Wastewater Emissions Per Unit of GDP	$\frac{Wastewater\ Discharge}{GDP}$
	Environmental Pollution Treatment Investment	$\frac{Investment\ in\ Environmental\ Pollution\ Control}{GDP}$
Green Society	Per Capita Education Spending	$\frac{Education\ Funding}{Total\ Population}$
	Per Capita Number of Health Facilities	$\frac{Number\ of\ Health\ Organizations}{Total\ Population}$
	Per Capita of Road Miles	$\frac{Road\ Miles}{Total\ population}$
	Per Capita of Park Area	$\frac{Park\ Area}{Total\ population}$

The widespread adoption of mobile payment services such as WeChat and Alipay is closely connected to the advancement of digital financial inclusion. As a carrier of mobile payment, the expansion of digital financial inclusion depends on its penetration rate. Therefore, we use the penetration rate of mobile phone to represent the development degree of digital financial inclusion, and the findings stay consistent with the regression results from the initial part(Table 9 column(2)). In the replacement of the model, this paper chooses to use the panel Tobit model to re-estimate the impact of digital financial inclusion on green development, and the test results are shown in the column(3), which shows that digital financial inclusion still has a significant positive impact on the green development.

Table 9:Results of Robustness Test

Variables	(1)	(2)	(3)
	Replacing Explanat-ory Variables	**Replacing Explanat-ory Variables**	**Replacing Model**
DFI	0.001***		0.002**
	(0.00)		(0.001)
Mobile		0.001**	
		(0.001)	
Gov	0.097	-0.473***	-0.233**
	(0.069)	(0.116)	(0.112)
Open	-0.001***	-0.001	0.000
	(0.000)	(0.001)	(0.001)
Fdi	0.007***	-0.006	-0.006
	(0.002)	(0.004)	(0.005)
Road	0.002**	-0.008***	-0.002
	(0.001)	(0.003)	(0.002)
Edu	-0.004	-0.015	-0.014
	(0.012)	(0.019))	(0.012)
Urban	0.477***	0.097	-0.032
	(0.108)	(0.162)	(0.112)
_cons	0.013	1.148***	1.036***
	(0.050)	(0.060)	(0.069)
Code	YES	YES	YES
Year	YES	YES	YES
Obs	240	300	300
R^2	0.830	0.465	/

4.4 Mechanism Test

In this section, we examine the detailed paths that digital financial inclusion takes to have an impact on green development. The regression results are shown in Table 10. Column (1) shows the results with the TL as a mechanism variable, each percentage point of DFI will drive the TL higher of 5.4 points. Column (2) is the results of TS, and for every 1 point increase in DFI, the degree of TS will increase about 5.4 points. In column (3), using Tech as the mechanism variable, the coefficient of DFI on Tech is positive and passes the significance test, which indicates that DFI can promote the progress of regional Tech level.

Table 10:Research on the Mechanism of the Impact of Digital Financial Inclusion on Green Development

Variables	(1) TL	(2) TS	(3) Tech
DFI	0.003***	0.005**	0.002**
	(0.001)	(0.002)	(0.001)
Gov	0.173*	2.175***	-0.172
	(0.093)	(0.547)	(0.126)
Open	0.000	-0.007***	-0.001
	(0.001)	(0.003)	(0.001)
Fdi	-0.004	-0.024**	0.023**
	(0.003)	(0.011)	(0.012)
Road	-0.005***	-0.018*	-0.005
	(0.001)	(0.009)	(0.004)
Edu	-0.018	-0.016	0.034
	(0.020)	(0.107)	(0.030)
Urban	0.355***	1.268	-0.353
	(0.123)	(1.096)	(0.243)
_cons	-0.149***	0.182	0.167
	(0.056)	(0.524)	(0.131)
Code	YES	YES	YES
Year	YES	YES	YES
Obs	300	300	300
R^2	0.261	0.832	0.644

4.5 Non-Linear Analysis

In the previous study, we got the conclusion that the development of digital inclusive finance can enhance green development level positively and significantly. So, does this demonstrate that digital inclusive finance may encourage green growth at any stage? We have observed that industrial structure optimization and upgrading, and technological innovation are the key mechanisms for digital inclusive finance to influence green development, and here, we choose to test the existence of the threshold by using the bootstrap method proposed by Hansen(1999), with three mechanism variables as threshold variables for 1000 sampling estimation. At first, we run three threshold test, and if all three pass, we believe there should be three thresholds in the model,if not, we run two threshold test and a single threshold test in turn.

The results are shown in Table 11. When TL and Tech are used as threshold variables, DFI shows a non-linear effect on green development, where TL has two thresholds and Tech has three thresholds. However, the TS has not passed any threshold test, so we have no reason to reject the original hypothesis that there are no non-linear effects of DFI on green development.

Table 11: Test Results for the Number of Thresholds After 1000 Samples Estimation

Variables	Threshold Number	P Value	Crit10	Crit5	Crit1
TL	Single	0.032**	39.117	51.526	72.356
	Double	0.020**	26.570	33.093	56.626
	Triple	0.494	41.899	55.762	90.375
TS	Single	0.266	38.937	48.905	67.775
	Double	0.168	36.1926	46.633	75.8779
	Triple	0.589	38.0668	44.7332	62.3268
Tech	Single	0.000***	35.714	42.591	56.336
	Double	0.060*	27.390	32.520	48.064
	Triple	0.079*	44.186	59.203	106.205

Table 12 shows the estimated values and confidence intervals of the thresholds when TL is used as the threshold variable. As shown in the table, the first value is 0.084 , and the second value is 0.374. Table 13 shows the regression results, when the TL is low, DFI has a negative effect on green development, but it is not significant; as the industrial structure gradually evolves to a reasonable interval, DFI begins to show a positive effect on green development, and this effect becomes significant when the value of this indicator is greater than 0.374.

Table 12:Estimation Results when TL as Threshold Variable

Threshold Number	Threshold Estimates	95% Confidence Interval	
Single	0.084	0.0789	0.088
Double	0.374	0.3665	0.378

Table 13:Regression Results when TL as Threshold Variable

Variables	Coefficient	Standard Error	P Value
TL⩽0.084	-0.035	0.229	0.877
0.084<TL⩽0.374	0.276	0.210	0.188
TL>0.374	0.769	0.206	0.000***
Gov	0.104	0.130	0.425
Open	-0.001	0.001	0.338
Fdi	-0.013	0.005	0.009***
Road	-0.009	0.004	0.020***
Edu	0.097	0.057	0.092*
Urban	0.350	0.460	0.447
_cons	0.723	0.273	0.008***

Table 14,Table 15show the threshold values and regression results with Tech as the threshold variable, the first threshold value is 0.111, the second is 0.176, and the third is 0.179. When the value of Tech indicator reaches above 0.176, the estimated coefficient is 3.7 times higher than that when it is less than 0.176, while when it is greater than 0.179, the estimated coefficient has a significant drop, but is still higher than the estimated value when it is less than 0.176. As a result, it is concluded that the Tech has an upward and then downward non-linear effect on the relationship between DFI and green development.

Table 14: Estimation Results when Tech as Threshold Variable

Threshold number	Threshold estimates	95% confidence interval	
Single	0.111	0.110	0.112
Double	0.176	0.174	0.177
Triple	0.179	0.177	0.186

Table 15:Regression Results when Tech as Threshold Variables

Variables	Coefficient	Standard Error	P Value
Tech⩽0.111	0.091	0.178	0.609
0.111<Tech⩽0.176	0.452	0.203	0.026**
0.176<Tech⩽0.179	1.673	0.359	0.000***
Tech>0.179	0.665	0.225	0.003***
Gov	0.283	0.154	0.065*
Open	-0.001	0.001	0.662
Fdi	-0.015	0.004	0.000***
Road	-0.007	0.004	0.081*
Edu	0.084	0.043	0.052*
Urban	-0.184	0.448	0.682
_cons	0.948	0.205	0.000***

5.Research Findings and Insights

In this paper, we estimated green total factor productivity using the SBM-GML method and examined the influence of digital financial inclusion on green development using panel data from 30 Chinese provinces from 2011 to 2020 as research samples, and we came to the following results.

(1)Green development in all regions of China have generally increased between 2011 and 2020, with most regions showing a rising trend following the 13th Five-Year Plan. (2)The coefficients of the three secondary variables are sorted from highest to lowest as coverage breadth, usage depth, and digital support, indicating that the impact of digital financial inclusion on green development is mostly through coverage breadth. (3)The impact of digital financial inclusion on green development can be divided into two paths: encouraging industrial structure optimization and encouraging technological innovation. When industrial structure rationalization is used as a threshold variable, two thresholds exist, and the influence of digital financial inclusion on green development strengthens as industrial structure rationalization improves. Three thresholds exist when technology innovation as a threshold variable, and digital financial inclusion on green development presents a non-linear effect that increasing first and then decreasing.

We propose the following policy suggestions based on the above analyses:

First, encourage traditional industries to transform toward low energy consumption and low pollution, reduce the dependence on high-energy industries, alleviate regional pollution problems, and improve green development. Make full use of digital financial inclusion in the process of green development, and improve the utilization efficiency of digital financial inclusion to encourage green development.

Second, promote the growth and application of digital technology, as well as the modernization of industrial structures. Digital financial inclusion can effectively broaden the financing channels of small and medium-sized enterprises,increase customer coverage in underserved areas, and effectively address the issue of development level insufficiency. Digital inclusive finance should fully exploit its information and digital advantages, increase support for innovation and green enterprises, provide appropriate green financial services for all industries.

Third,enhance science and technology innovation policies and boost competitive edge of innovative enterprises. Strengthen efforts to attract high-end talent, provide a favorable business environment for high-tech firms, construct high-tech industrial zones, apply preferential development policies to attract high-tech enterprises to settle down and accelerate the formation the high-technology industrial cluster.

This paper still has some weak points: Firstly, regarding the measurement of green development, we expressed it by using green total factor productivity, however, this method may not entirely depict green development, and a more ideal indicator system in accordance with the definition of green development will need to be constructed in the future. Secondly, the synergy between digital financial inclusion and green finance is not taken into consideration, in the following research, we can further investigate the impact of green finance and give a more scientific and fair opinion reference for green development.

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